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THE FOOD RESOURCES OF THE SEA

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PRIMITIVE man got his food as his competitors did—that is to say, he picked it up or killed it where he could find it. Very early in his civilized career he ceased to be a hunter and began to cultivate the land; in fact, the beginnings of civilization and of agriculture were contemporaneous. Since that time the pressure of increasing populations demanding to be fed has been a prolific source of human strife. There are not lacking economists who would maintain that the recent catastrophic war in Europe was the direct result of an increasing demand for food on the part of the rapidly multiplying German nation. East, in THE SCIENTIFIC MONTHLY for December, 1921, points out that the agricultural resources of the United States can in all probability not support in reasonable comfort more than two hundred million people and that the present indications are that our population will reach that figure within the next century. Furthermore, we can not count on importing food indefinitely, since by the time our own population reaches its limit, the now scantily peopled parts of the world will produce little or no food in excess of the needs of their own greatly augmented populations. His is but one of many voices warning us that there is a limit to the number of human beings whom the earth can support, and however we may disagree with the various estimates as to what the limit may be, we can not doubt that it exists, and that, historically speaking, we are rapidly approaching it. The purpose of this article is, however, not to consider this question in detail, but merely to point out one source of food of which the possibilities are still largely unrealized.

If we were to-day still depending upon the chase as the main source of our food, most of us would be dead, or, rather, we should never have been born. Yet so far as the oceans, which cover three fourths of the surface of the earth, are concerned, we have made little essential advance over the methods of the primitive fishermen. The flocks and herds of the sea still roam freely in their native haunts, and we cast our lines and nets over their feeding grounds, and catch what we can. Our operations are on a larger scale, it is true, than those of our predecessors, our tackle is superior, our nets larger and stronger, and, by equipping our fishing vessels with steam or gasoline power, we have enlarged the area we can cover. Once the fish are landed, we have an elaborate system of distribution and marketing, so that cities a thousand miles inland can have fish a day out of the ocean shipped to them in fast refrigerated cars. There is also a little direct utilization of the plants of the sea. In certain parts of the world, notably in China and Japan, and to a less extent in Europe, a few of the algæ are eaten by man or his domestic animals, or gathered to be utilized in some minor industry. But so far as the actual cultivation of the sea's resources as distinguished from their mere exploitation is concerned, we have made only the feeblest beginning. The reasons for this are, of course, the uncontrollability of the sea as compared with the land; its instability; the vastness of the oceans and the relative inaccessibility of much of their area; and especially the difficulty of attempting to control living organisms in the sea, out of man's natural element, as they may be controlled on the land where he is at home. Yet if the demand becomes insistent enough we can not doubt that methods will be devised which will give us the desired results. To question that would be to admit that man has neared the culmination of his evolutionary career and is preparing to bequeath the mastery of the earth to his successor, whoever that may be.

The bulk of the food supply which we have come to expect the ocean to furnish us is animal. Animals that live in the sea are, however, no less dependent upon plant life for their food than are land animals. We all know that the beef we eat is built up from the grass and grain upon which the cattle have fed; and, while there are many animals that feed upon other animals only, sooner or later the cycle goes back to the green plants. This is because the green coloring matter contained in plants is the only substance known that can so combine carbon and water as to form the carbohydrates that are the fundamental materials of which all living beings, whether plants or animals, are constructed. The plants living in the sea are then the equivalents, so far as the life of the sea is concerned, of the land plants. Like land plants, they not only need carbon and water, but certain mineral salts. Of these, those that furnish them with nitrogen and phosphorus are most important, since they are most apt to be present in insufficient quantity and thus to be limiting factors. The plants in the sea are continually using these substances and are continually dying or being eaten by animals. Sooner or later there comes a time when by the death and decay of the plant or animal most of these materials are returned to solution. Part, however, have been transformed into insoluble compounds and are lying inert in the depths of the ocean. Thus there is a constant loss of nutrient salts. This loss is replaced by drainage from the land, the great rivers carrying constantly into the ocean an almost incredible amount of dissolved minerals in addition to suspended matter.

Another important requirement of plants is light. Plants on land receive the full benefit of the sun's rays as we know them. Plants living under water receive only a portion of the rays that reach the land. Part of the light that strikes the water is reflected, and the part that penetrates the water is gradually absorbed in passing through that medium, the red and yellow rays first, the blue and violet last. This differential absorption is reflected in the curious and well-known vertical distribution of marine algæ according to color—the green kinds growing in shallow water, the browns in an intermediate zone and the reds in the deepest water, although there are, of course, numerous exceptions to this general rule of distribution. Another property of light is that it is refracted by water, and the greater the angle at which the rays strike the water the greater will be the refraction. In the tropics, where the rays are practically vertical, the amount of refraction is insignificant, but in high latitudes, where the rays strike the water at a sharp angle, the refraction is marked, as a result of which the rays are bent into a more nearly vertical direction, thus increasing their penetration in depth and partly compensating for the unfavorable angle at which they strike the water. The penetration is also markedly affected by the amount of suspended matter and the number of microorganisms present in the water. Helland-Hansen was able to show that in the Atlantic Ocean south of the Azores, on a bright summer's day, light is abundant at a depth of 100 meters, still including at that depth a few red rays. At 500 meters the red rays have completely disappeared, but blue and ultra-violet rays are still plentiful, and may be detected at 1,000 meters, but have completely disappeared at 1,700 meters. It is not probable, however, that under the most favorable conditions photosynthesis may be carried on at depths greater than 200 meters.

Temperature is less directly important in the sea than on land since there is no great danger of injurious extremes being reached. Indirectly, its importance lies in the fact that carbondioxide is much more soluble in cold water than in warm, (Fig. 1) and it is probably this, rather than the direct influence of temperature which accounts for the fact that the most luxuriant development of plant life is in the colder waters of the earth.

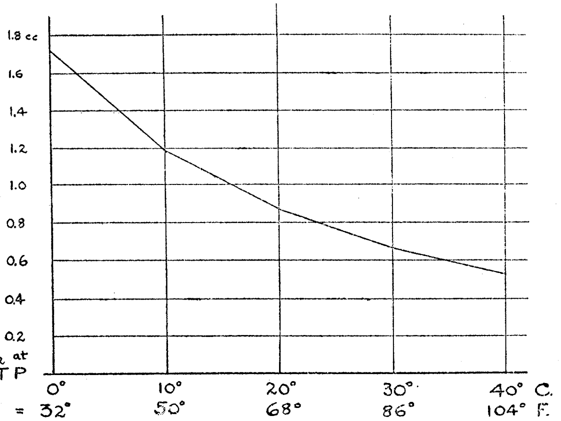

FIG. 1. SOLUBILITY OF CARBON DIOXIDE IN WATER. CUBIC CENTIMETERS OF CO_2 SOLUBLE IN 1 C. C. OF WATER, REDUCED TO NORMAL TEMPERATURE AND PRESSURE

On the basis of habitat, marine plants may be divided into two great groups. On all coasts, and in shallow waters near the coasts, there is usually a conspicuous zone of "seaweed." This is known as the benthos, from a Greek word denoting bottom, because it occurs attached to the bottom on the shelf of shallow water surrounding the coasts. The plants of the benthos are extremely varied and range in size from microscopic to very large, the giant kelps of the northern Pacific sometimes reaching a length of nearly four hundred feet. We are accustomed to think of these plants as algæ, and most of them belong to one or another of the great algal groups, but the most important of all the plants of the benthos is not an alga but a flowering plant, belonging to the pondweed family, and not very distantly related to the grass family, which is the most important economic family of land plants. This is *Zostera marina,* the common eel-grass. *Zostera marina* or some of its near relatives occurs on almost all the ocean shores of the globe, being absent only in the extremely hot and extremely cold portions. It grows in water varying from a little over a meter in depth at low tide, to depths of fifteen or twenty meters in certain clear Mediterranean waters; and in waters varying in salinity from that of the sea water of the open ocean to that of brackish bays and estuaries of less than half full salinity. It prefers mud, but will grow nearly as well in sand. It will not grow, however, where the bottom is composed of loose stones nor where the wave action is severe, and these localities are inhabited by the true algæ. The windrows of dead "seaweed" commonly found cast up on our Atlantic shores are very largely composed of *Zostera.* A few other flowering plants occur in salt or brackish water, but they are relatively unimportant.

The algæ of the benthos occur, as previously stated, in three rather indefinitely limited zones. In the quiet waters of shallow bays we find a great many green and blue-green algæ. Such forms as *Ulva lactuca* and *Enteromorpha intestinalis,* both often called sea lettuce, are typically found in such situations. The branching, feathery masses of *Cladophora* and the thick green felt of *Vaucheria* are also often prominent. The blue-green algæ are entirely microscopic, but often occur in great abundance. A species of *Lyngbya* frequently forms felted mats two or three inches thick and many feet across. Masses of *Spirulina* as large as a dinner plate are common. The plants which grow between tide levels or just below low tide, at places where there is considerable wave action, belong mostly to the brown algæ. Various rockweeds, belonging to such genera as *Fucus* and *Ascophyllum,* are common in northern waters, and the gulfweed, *Sargassum,* is typical of the forms growing in the warmer waters. Below low tide level the great kelps—the Laminarias and their allies—are the largest plants of the ocean, the larger species occurring, however, only in the cooler waters. The algæ of the deeper waters are mainly the reds, and the farther south we go the greater becomes the preponderance of the red algæ. It must be remembered, however, that red, brown, green and blue-green algæ are more or less intermingled at all depths and in all latitudes. All the plants we have been considering are alike, however, in that they occur only near the shores, except in cases where they have been torn loose from their fastenings and carried by currents into the open sea. The Sargasso Sea of the Atlantic Ocean is merely an area outside of the track of the great oceanic currents and therefore constituting a huge eddy in which such material accumulates, growing vegetatively to a certain extent and finally dying and sinking.

If the only marine plants were in the benthos, in spite of the local luxuriance of its growth, the great mass of the ocean would be a desert, incapable of supporting anything like the amount of life which actually exists in it. There is, however, another great group of living organisms, the plankton. The plankton comprises those plants and animals that are neither attached to the bottom nor able to swim against a current, but normally live floating in the water and carried by it from place to place. Some of the animals of the plankton are of rather large size—such, for example, as the Portuguese man o'war and some of the larger jellyfish. Most of them, and all the plants, are microscopic. The plants, in fact, are all unicellular, although the cells are often united into filaments or colonies of various shapes. Two groups of plankton organisms are of special importance: the diatoms and the peridines.

The diatoms are unicellular plants occurring in all waters, but especially abundant in the colder parts of the ocean, growing in enormous numbers in the Arctic and Antarctic regions and reaching in temperate waters their maximum development in the cooler months of the year. They are unicellular organisms, enclosed in two silicious shells, one fitting over the other much as the lid fits the bottom of a pill box. In shape they are extremely varied, and the shells are usually marked with intricate patterns and often decorated with spines and knobs.

The peridines constitute a curious group of unicellular organisms intermediate between plants and animals. Some of them are holophytic or plantlike in their method of nutrition, others are saprophytic, absorbing dead organic material dissolved in the water, some are parasitic in the body cavity of small animals, such as copepods; a large number are holozoic, capturing and ingesting their food just as animals do. The peridines very largely replace the diatoms in the tropical seas, and in temperate waters attain their maximum numbers in the warmer months when the diatoms are at a minimum. This seasonal distribution is very possibly correlated with the diminution of the carbon dioxide content of the warmer waters. The peridines may be naked, or provided with a simple or elaborate armor of cellulose, the same material as that of which plant cell walls are composed. Whether armored or not, they are always provided with two flagella, one, hair-like, which trails behind them, the other a ribbon-like undulating structure typically encircling the body in a special groove provided for it and giving to the organism a rotatory motion.

In spite of their minute size it may fairly be said that the diatoms and the holophytic peridines are to the ocean what the grasses are to the land. What they lack in size is more than compensated for by their extreme abundance and rapidity of reproduction. Under favorable conditions hundreds of thousands of them may exist in a liter, so that the water is distinctly colored and is almost soupy to the touch.

A third group of important plankton organisms, entirely holophytic in their nutrition, is known as the *Coccolithophoridae*. These are brown-pigmented forms secreting very regular calcareous shells and occurring in the warmer parts of the open ocean. Most of them are extremely minute and while they are known to occur in extremely great abundance at times, because of their small size little is definitely known about their distribution or relative importance.

In addition to these groups of organisms, the zoospores and gametes of algæ are liberated in enormous number at certain seasons of the year, and add their contribution to the food supply of the plankton, while there are numerous brown and green flagellates belonging to other than the three groups mentioned.

The phytoplankton exists everywhere at the surface of the ocean and for a considerable depth below the surface. Certainly it is fairly abundant as far down as a hundred fathoms in those parts of the ocean where the light approaches the vertical. It is, however, much more abundant near land than in mid-ocean, mainly because the organisms near land are in more immediate contact with the nutrient materials washed from the land into the sea, and tend to exhaust the supply before these materials reach the open ocean. The ratio between the number of plankton organisms near land as compared with the number in the open seas has been given as fifty to one, but this estimate, for reasons which will be apparent later, is probably much too high.

It is not enough to know life in the ocean qualitatively. It was long ago realized that it must be analyzed quantitatively. The earliest quantitative studies were those of Hensen, beginning about 1880, and modern work on the problem may be said to begin with him. He devised the forerunner of the present-day plankton net and attempted to account for the production of the sea by his collections. His nets missed all the smaller organisms and failed to secure many of the larger ones. Hensen realized this and attempted to allow for it in his calculations but his results were necessarily very imperfect. He succeeded in imparting new impetus to such studies, however, and deserves the credit due to a pioneer worker in a difficult field. The amount of food required by the animals of the sea is so much in excess of the amount shown to be produced by these early methods that Pütter (1907-1909) argued that the nutrition of marine animals was on an entirely different plane from that of land animals, and that a large number of them, especially the smaller ones, absorbed dissolved organic matter directly from the water without the mediation of plants. Pütter's arguments have not been generally accepted and more recent studies have invalidated many of them. Nevertheless, it is possible that something of this sort is more general than we realize. Mitchell has recently (1917) reported on experiments strongly indicating, although perhaps not proving, that so highly organized an animal as an oyster can utilize dextrose dissolved in sea water, transforming it into glycogen and storing it.

In 1911 Lohmann showed that many of the organisms that pass through the plankton net may be secured and studied by the use of a centrifuge. This, again, marked a great advance. He showed that these smaller organisms, for which he proposed the convenient term ''nannoplankton,'' existed in enormous numbers in parts of the sea which the net collections seemed to show were barren, and found that certain animals—*Appendicularia* e. g.—were very efficient collectors of these minute forms, sometimes feeding on them almost exclusively. Gran reports a similar experience in the Straits of Gibraltar. Net collections showed very little plankton in the water, but the stomachs of *Salpae* when examined were found to be crammed with forms too small to be retained by the nets. Even centrifuging fails to get many of these forms since they are often lighter than water or as light, or are so delicate that the operation destroys them. Allen has devised a dilution culture method similar in principle to those used in making bacterial counts. He adds to a quantity of filtered sea water a few drops of a nutrient solution, sterilizes it, and adds to it a known quantity of the sea water to be investigated—say, one cubic centimeter. After thorough shaking, this is poured into about a hundred sterile flasks and put in a north light for a few days. The flasks are then examined and the organisms that have developed in them identified, and the number of different kinds that are found in each flask are recorded. A given species is recorded only once from each flask and since at least one individual of the species must have been introduced to permit such development, the count is still too small. By actual experience this gave results of 464 organisms per cubic centimeter or 464,000 to a liter. Bacteria were disregarded. The centrifugal method applied to the same water gave a count of 14,450 to a liter. Allowing for duplication in some of the flasks and for the failure of many forms to develop under laboratory conditions Allen concludes that a count of 1,000,000 organisms per liter would be conservative. That is, one organism to each cubic millimeter. Assuming an average size equivalent to a sphere with a diameter of five microns, that is not excessively crowded, as the diagram will show. (Fig. 2.)

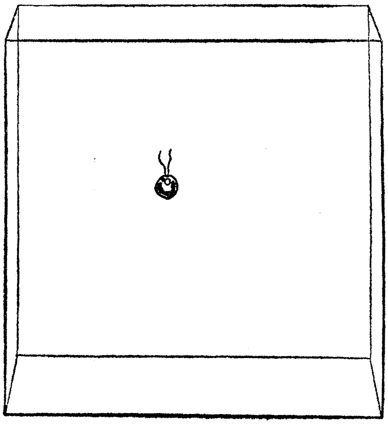

FIG. 2. COMPARATIVE SPACE OCCUPIED BY AN ORGANISM 6 MICRONS IN DIAMETER IN A CUBIC MILLIMETER (1/1,000,000 LITER) OF WATER

In this country, Moore, followed by Grave, attempted to calculate the "food value" or areas of water on the basis of similar plankton counts, working with special reference to the nutrition of oysters. They found out what organisms occurred in greatest numbers in the oysters' stomachs, studied the rate of feeding and then proceeded to collect and analyze samples of water over actual or potential oyster beds, finding out just how many of these organisms occurred to the liter. They then carefully calculated the volume of each organism and by multiplying the volume by the number of times a given organism occurred in a unit volume of water and adding the totals, the "food value" was secured. This method gave much valuable information, but the results can not be regarded as final for several reasons. For one thing, organisms differing so widely as diatoms and peridines are not comparable on the basis of their volumes, as has been pointed out by Brandt and Juday. Again, in a locality where oysters are not naturally growing, their introduction often materially increases the supply of food, since their shells form substrata and their excreta help in the nourishment of numerous food organisms. Finally, they took no account of the food value of the nannoplankton nor of the detritus, which may be very considerable.

The most elaborate attempts to calculate the production of the sea have been those of the Danish biologist Petersen and his associates. As a result of their studies, these workers have come to the conclusion that the plankton plays a very small part in the nutrition of the animals of the sea and that the fundamental food of all marine forms in northern waters at any rate is the "dust-fine detritus" of the sea bottom, derived primarily from the eel-grass, *Zostera*. As an indication of the degree of progress which

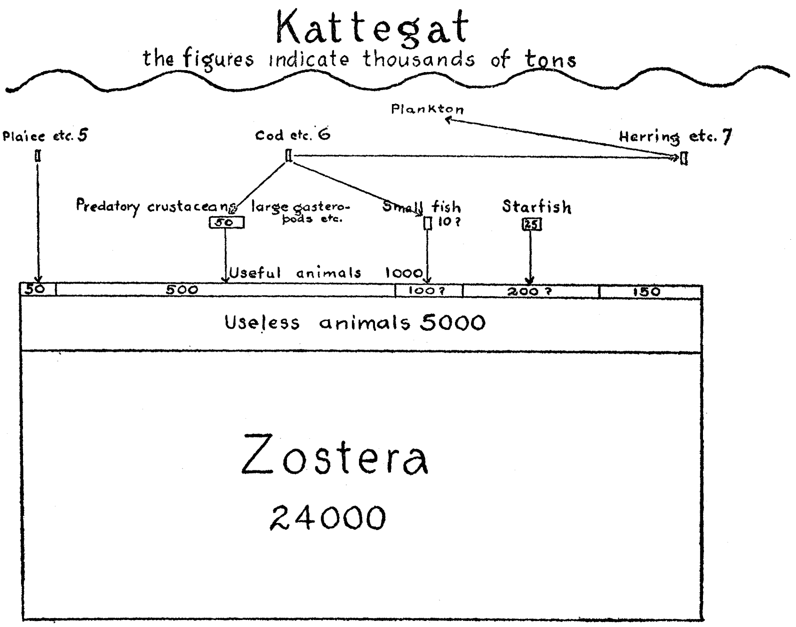

FIG. 3. ANIMAL LIFE IN THE KATTEGAT DERIVED FROM ZOSTERA, AFTER PETERSEN

these workers have made, the preliminary conclusions in the life in the Kattegat may be cited. The Kattegat is the rather shallow body of water between eastern Denmark and Sweden, having an extreme length of 150 miles and an extreme breadth of about 90 miles. It is assumed that about half of the total amount of *Zostera* annually produced in this area is washed elsewhere by the currents. The balance, estimated at 24,000,000 tons, serves as the basis for the animal life of the area. (See chart, Fig. 3.) The useless animals, that is, those that are of no value to man and do not serve as food for fish, feeding directly on the Zostera, amount to about 5,000,000 tons. Useful animals, mainly those capable of serving as food for fish, are estimated at 1,000,000 tons. These are not all utilized by food fish, however. Starfish account for perhaps 200,000 tons; 500,000 tons are eaten by the larger gasteropods and crustaceans, of which only a part are consumed by fish; while plaice and other flatfish consume about 50,000 tons, producing 5,000 tons of human food annually. Cod are much less economical, since they get their food at third hand, so to say, and each ton of the 6,000 tons produced annually represents about one hundred times as much of the original synthesized organic food. On the other hand, the cod help to keep down the predatory gasteropods and crustaceans. The herring is the most important food fish feeding on the plankton, (mainly on copepods) and it in turn is eaten by the cod. Perhaps the most striking feature brought out by these figures is the comparatively trifling amount of human food finally produced from such a large amount of organic material.

So much, then, for the life naturally existing in the ocean. How may our utilization of it be more intelligently directed? Obviously the most economical use of it as food would be for man or his domestic animals to eat it directly. So far as the use of algæ as food for human beings is concerned, we cannot expect, for the present at least, any considerable increase over the insignificant amount now consumed in the United States. In some countries algæ have been used as food for stock for centuries, and recent experiments have indicated that cheap and effective treatments may make possible a substantial increase in such use. It has recently been shown that the kelps exhibit wide variation in their carbohydrate as well as in their iodine content during the growing season and future utilization, to be profitable, must take such fluctuations into account so that the plants may be harvested at the proper season. We would not think of doing anything else in the case of a land plant. And it may be mentioned in passing that the old method of burning kelps for potash and iodine content cannot be regarded as anything but a wasteful process even when temporary conditions permit it to compete with other sources of these products, as during the world war. Recent experiments in Sweden have suggested that dry distillation will yield, not only the potash and iodine formerly sought, but numerous other products, including illuminating gas, acetic acid, methyl alcohol, formic acid, acetone and creosote.

Since, however, man prefers to harvest the plant life of the sea indirectly, those animals which feed directly on the plants are able to increase with less waste and at a more rapid rate, considered in total populations, than those which feed on other animals. Most of our food fish, for example, feed on smaller fish; these in turn feed upon small crustaceans and the latter eat the microscopic plants and detritus, so that in many instances the fish we eat are removed three or four steps, perhaps more, from the original food source. This is more significant than may seem apparent at first glance, since it involves an enormous waste. Before any organism can grow, the energy needed merely to live must be supplied, and by the time a crustacean is eaten by a minnow, or a minnow by a food fish, it will, on the average, have consumed a quantity of food several times its own weight. These facts are well brought out in the diagram and statistics of Petersen, previously quoted. The edible shellfish, however—oysters, clams, mussels and the like—feed for the most part directly on the marine plants and this is one reason why the extension of the shell fisheries represents so much promise.

The carp is one of the few edible fish which lives directly on vegetable food. In the United States most people do not, it is true, regard this species as particularly edible but since it is largely eaten in Europe and raised for the purpose, it will serve as an excellent example of what such a fish may produce. The statistics on this fresh water fish are particularly valuable because they are not subject to the sources of error which hamper attempts to measure the productivity of the sea. The amount of fish produced in carp ponds has been calculated as ninety-five pounds on the average each year per acre. Brandt calculated the productivity of Kiel Harbor as eighty-nine pounds per acre annually, but the latter figures are much less exact. The average yield of beef on good land in the United Kingdom is seventy-three pounds per acre annually. The beef is much superior in food value, pound for pound, but it is also much more costly to produce. There are many inlets of the sea where conditions are almost as readily controllable as they are in the fresh water ponds. Such, for example, are the shallow enclosed sounds on the Atlantic coast of the United States

—Great South Bay in Long Island, Barnegat Bay in New Jersey, Albemarle and Pamlico Sounds in North Carolina and parts of Chesapeake Bay. These enclosed areas are at present producing a great deal of human food, but only a small part of what they might produce under proper management. On a larger scale, the Baltic and North Seas of Europe are similar regions where, if not sea culture, at least an intelligent harvesting of the seas' resources is yearly becoming more possible because of the careful studies which have been made by the English, German and Scandinavian biologists, whose countries are chiefly interested in the matter.

Before we can expect to make substantial advance we must have a much more comprehensive knowledge of the ecology of the sea than we have at present. For example, we may class the animals of the sea roughly into those which are valuable to man and those which are not, but when it comes to determining to which of these classes any particular species belongs, difficulties arise. The difference which direct and indirect utilization of food makes has already been pointed out. Some useful species which get their food at second or third hand, that is, by eating other animals, prey largely on forms that would not otherwise be converted into human food; some, on the other hand, eat species that are good human food. Thus, drumfish are good human food, but they may at times consume large numbers of oysters which are still more valuable to man than they are. Starfish, which are utterly useless forms, also attack oysters, but this case offers no perplexities. A very large number of animals are useless in the sense that they occupy space and consume food which might otherwise be utilized by useful species. The snails, sponges, sea anemones and some of the mussels of our northern waters belong to this group. However, in the case of most marine animals only a complete account of their life histories, together with the life histories of their associated forms is sufficient to enable us to know whether they are, in the long run, valuable or harmful from the human standpoint and whether it would be wise for us to attempt to overturn the balance which we find them maintaining in nature.

Another phase demanding careful study is the effect on the marine life of the waste materials which are constantly being poured into our waters, especially in the vicinity of our great cities. So far as industrial wastes and oil are concerned, the effect is wholly bad, and the questions at issue are: How much of this discharge is necessary? How can the pollution best be restricted to the necessary minimum? The sewage problem is more complex. The addition of large amounts of rich nitrogenous fertilizing material to our waters could be made a great source of wealth if it were properly utilized, and even under our present hit or miss methods it results in a marked enrichening of the marine flora in favored localities. On the other hand, the danger of disease transmission is so well recognized and is illustrated by so many striking examples that large areas of sewage-polluted waters are eliminated as sources of food in whole or in part. How to utilize this valuable asset without endangering public health or spoiling the recreational value as well as the food value of our coastal waters is one of the biological problems of our day.

Finally, it may be reiterated that shellfish culture offers the most immediate hope for effective utilization of the sea's resources. The economy of direct utilization of plant food by these animals has been emphasized. Most shellfish, like land crops, stay where they are planted. Even the scallop, which can swim about after a fashion, is restricted in its movements and could readily be controlled. Oyster culture is already a great and important industry but it has not nearly approached its possibilities. Clam culture is still in an embryonic stage and scallop culture has as yet merely been suggested. When some of the problems confronting the establishment of these industries have been solved we may hope to have acquired additional information concerning the ecology of the sea which will help us in our approach to the more difficult problems of the future.

It is recognized that there are numerous economic phases involved in attempts to increase the productivity of the sea, but consideration of these would be beyond the scope of this paper. When social and economic forces demand additional food at reasonable prices, the biologists must be prepared to show where and how this may best be obtained.